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The effects of environmental transport policies on the environment, economy and employment in Portugal

Pedro Nunes [a, b, *], Fábio Pinheiro [b], Miguel C. Brito [a, b]

[a] IDL - Instituto Dom Luiz, University of Lisbon, Portugal
[b] Faculty of Sciences of the University of Lisbon, Portugal

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ABSTRACT

The transport sector, accountable for a large share of climate change and pollution, is on the verge of changing over the coming decades. To lead it through the best path, carefully designed public transport policies are needed, since they have several important secondary effects on the society and economy. However, their assessment is not straightforward, as the transport sector comprises millions of actors with heterogeneous behavior. This study estimates the impacts of the promotion of market- and command-and-control based pro-environmental transport policies on the mobility, environment and economy. For the case study of Portugal, several sets of policies until 2050 were tested by means of a ‘what-if’ type policy analysis using the ASTRA-EC model, and the results were compared with a business-as-usual scenario. The results show that the policies are effective at shifting passenger travelling to public transportation, but care must be taken when promoting the market deployment of clean vehicles or penalizing those less clean, due to a rebound effect on car usage. The largest CO_2 emissions reductions (26%) are related to the application of policies promoting the deployment of electric vehicles, suggesting that this is an essential measure to curb emissions. It was also observed that cleaner vehicles complying with post-Euro 6 emissions standard are important at reducing pollutants (by up to −27%). This happens at the same time as economy is improved by 0.5−1.1% and employment by 0.22%, i.e., tackling the issue of transportation is synergic with the economy. Despite the encouraging results in relative terms, absolute transport emissions in Portugal in 2050 increase by at least 15% in relation to 1990, far short from the environmental objectives to significantly cut emissions.

1. Introduction

Transportation is the prime sector contributing for greenhouse gases (GHGs) emissions in the European Union (EU), accountable for 27% of the total emissions in 2016 (European Environment Agency, 2017). Land transport, i.e., by road and railways, accounts for around 74% of transport emissions, where road is almost fully responsible for this share (72%). To complicate matters, transport emissions have been increasing in the past few years: relative to 2015, they rose in 2016 by 18.6 Mt of CO2eq, or 2.1% (European Environment Agency, 2016). This may compromise Europe's climate-energy goals of 40% overall emissions cuts by 2030, 60% by 2040, and at least 80% by 2050[1] (European Commission, 2011). In transportation the cuts aimed are of 60% by 2050 (European Comission, 2011); those reductions are essential to comply with the Paris Agreement, in order to contain climate change. Moreover, transport pollution, especially from urban road transport propelled by diesel, is considered the biggest environmental health risk in the EU, harming severely the environment and human health, e.g. fine particulate matter causes each year the premature death of more than 450,000 Europeans (Guerreiro et al., 2016). This is a worrying state of affairs, requiring urgent actions and innovative policies to address it.

One way to tackle the problem is by means of the application of centralized clean transport policies, whose results depend on their effects on the modal split, fuel type adopted, energy efficiency and transport volume (Grazi and van den Bergh, 2008). Examples of the aims of those policies may be the stimulation of public transportation use and curbing private dislocations – in Europe, buses and coaches represent only about 8% of passenger trip volume and railways 6%, whereas private cars represent 74% (European

* Corresponding author. IDL - Instituto Dom Luiz, University of Lisbon, Portugal. *E-mail address:* pmnunes@fc.ul.pt (P. Nunes).
[1] Relative to 1990.

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Commission, 2014) –, or the diffusion of electric mobility – electric vehicles (EVs) impact much less on climate change and urban air quality than conventional vehicles (Messagie, 2017). Such policies have several important indirect effects on national economies, such has in employment and in the gross domestic product (GDP), which are thus necessary to consider in the policies design. Policy induced effects frequently give rise to changes in quantities and prices in markets, and so a dynamic economic analytic perspective must be taken (De Bruyn et al., 2012). The results are difficult to quantify, given the complex dynamics of the economy.

Nonetheless, there is general agreement that the net effect of environmental policies is positive for the economy, e.g. by increasing the efficiency in the use of resources and energy, or by increasing net employment, in particular green jobs. A green job may be understood as one that contributes to the decrease of the society environmental footprint (International Labour Office and Organisation for Economic Co-operation and Development, 2012), such as jobs that have as result the benefit of ecosystems and biodiversity, reduction in energy, materials and water consumption, economy decarbonisation, and waste and pollution minimization (UITP, 2013). In this sense, the collective transport sector and the electric mobility industry are creators of green jobs[2] (Rayment et al., 2009).

Investments in transport infrastructure, making the system more efficient and generating employment and added value in the transport sector and in the up- and downstream sectors, contribute to economic growth (Meersman and Nazemzadeh, 2017). However, they come with environmental externalities, e.g. increased pollution, and so it is essential their combination with pro-environmental policies (Ponti et al., 2013) including promotion of public transport use by reducing fares (Hess, 2017); incentives to the development and deployment of less polluting vehicles – there are several potential technical improvement options which may be incentivized (Leduc et al., 2010); city planning measures to reduce congestion and to provide alternatives to private cars (Leo et al., 2017), or strategies aimed at reducing travel demand (Redman et al., 2013). The revenues from environmental taxes, such as a tax on transport emissions or pricing schemes to tackle congestion, if used to lower other taxes, such as on labour, can contribute to make environmental, employment and social policies synergetic (International Labour Office and Organisation for Economic Co-operation and Development, 2012). However, instruments that aim to improve the environmental performance of transport policies are often ineffective because of the many trade-offs taking place and unanticipated adverse effects of isolated measures (Vieira et al., 2007).

This study uses an integrated dynamic method to assess the effects on the economy and environment of the application of packages of transport policies to increase sustainable mobility, assessing their potential effectiveness. It contributes to enhance the understanding of intersectoral results of transport policies, using a 'what-if' type policy analysis. For that, it was developed a framework consisting of a multi-policy approach based on market-based and command-and-control and public investment mechanisms, using scenarios until 2050 for Portugal.

The paper proceeds with the presentation of previous recent studies on transport policy that are relevant to frame the present study. The approach is presented in Section 3, to which follows a description of the case study in Section 4. The results and discussion are in Section 5, before the conclusions in Section 6.

[2] Overall, one in six jobs in the European Union are related to the environment, directly or indirectly (Rayment et al., 2009).

2. Previous relevant studies

Baptista et al. (2012) presents a methodology that can be used to develop scenarios for the evolution of energy consumption and emissions on the road transportation sector, which has been applied to Portugal for the period 2010–2050. The study concludes that since there is a delay in the fleet impacts of technology improvements due to a slow fleet turnover, current internal combustion engine (ICE) technologies determine the near-term energy consumption and emissions results of scenarios. Thus, efficiency improvements on conventional vehicles have greater impacts in the short-term than alternative technologies, which are more effective at producing results in the long-term. The work also concludes that policies on taxation and alternative transportation modes, including public transport, are crucial for achieving short-term impacts. (Braz da Silva and Moura, 2016) aimed to identify the extent to which electric vehicles can diffuse in Portugal, taking a car demand perspective, and they compared several evolving scenarios for the EV market against a reference scenario. It was concluded that a fast-growing economy is the most important driver to make energy and carbon intensity decrease, due to faster gains in efficiency. The authors also conclude that, concerning policy instruments, the taxes applied to fossil-fuels and to conventional vehicles are the most effective policies to increase the penetration of EVs – which, in any case, will remain low at least until the end of next decade. Seixas et al. (2015) uses a partial equilibrium model to assess the cost effectiveness of EVs in the European Union Member States until 2050, concluding that EVs will start to be cost-effective by 2030, but only if their costs drop 30% below what is anticipated. It was also found that the EVs cost and driving range are the main conditions to their deployment, therefore, because electric mobility depends on policy instruments to initially breach into the market, incentives to decrease costs determine its deployment. From an energy system viewpoint, the study showed that a careful analysis is needed when designing policies and instruments to promote electric mobility.

Magueta et al. (2018) applied multiple regression analysis to a dataset of new cars sold in Portugal during the period 2002–2016 to identify correlations with macroeconomic variables. The results show that factors such as characteristics of household and cities are important to consider when designing new environmental policies. It was also shown that in Portugal taxation benefits have strong positive impacts over EVs sales, and that adoption of these vehicles does not necessarily translate into higher environmental consciousness of the buyers, but rather a cost-effectiveness consciousness. Lorenzi and Baptista (2018) addressed the progresses observed in Portugal towards a cleaner transport sector, analysing the effects of scenarios that include the trends in renewable energy and technology adoption. It was shown that EVs are the most effective way to reduce energy consumption and emissions, while synthetic natural gas-based vehicles would take advantage of endogen resources. The paper also shows that at least in the next one and a half decade the transport sector in Portugal will continue to be dominated by fossil fuels, however this can be limited by applying well designed subsidy schemes to alternative technologies, such as EVs. Alam et al. (2018) addressed the effects of climate change mitigation policies in reducing air pollution produced by passenger cars, analysing scenarios until 2035 for Ireland. The results point to a large reduction in CO_2 emissions by 2035 (up to around 60%), which are not followed by the same magnitude of PM2.5 emissions reductions (up to 15%).

Evangelista et al. (2018) addressed the environmental sustainability of third-party logistics service providers, which, given the growing demand for moving goods, is increasingly important to achieve a cleaner supply chain. The authors carried out a

thoroughly literature review on the subject, which allowed to identify some research gaps and a set of directions for future investigation. Although the number of publications on the subject has grown significantly in last ten years, the areas of information and communication technology and performance measurement are still largely unaddressed. For example, it was found a gap regarding integrated analyses of the environmental benefits arising from the adoption of information and communication tools, or a gap in what regards the existence of suitable indicators and shared performance metrics, which constitute also future research areas to address.

A wider review on measures directed to greening the road passenger transport sector was carried out by Moriarty and Honnery (2013), where it is evidenced that technical solutions *per se* are not even close effective at achieving the reductions in emissions that are needed. The paper examines also non-technical solutions, concluding that transport policies should aim to reduce passenger travel needs, since this is the most effective way to produce emission cuts.

For an easy glance through the studies addressed in this Section, Table 1 summarizes and classifies them according to territorial scope, period analysed, methods, objectives and main results.

3. Methods

The simulation of the application of policies and scenarios was performed in the ASTRA-EC model, described in Section 3.1. The model setup is explained in Section 3.2, and the limitations of the approach are identified in Section 3.3.

3.1. The ASTRA-EC model

The ASTRA-EC is a computational model developed under the European project ASSIST - Assessing the Social and Economic Impacts of Past and Future Sustainable Transport (ASSIST, 2017) to identify and evaluate social, economic and environmental impacts associated with transport policies in European countries. It was developed for the European Commission in order to provide an instrument to strategically analyze policy proposals (Fraunhofer-ISITRT Trasporti e Territorio, 2017) in the EU. The model covers the period 1995–2050 working with annual time steps, and includes eight modules characterized by different variables. Table 2 lists the main modules and the corresponding variables, and each module is briefly described below.

The population module reflects the population evolution for 29 EU countries, depending on fertility and death rates and immigration. It interacts dynamically with other modules, providing them information such as the number of people within working age or able to acquire a driving license. The population module is calibrated according to the EUROSTAT population projections.

The economy module reflects the economic framework, deeply interlinking with other modules. It considers production functions (e.g. to obtain the amount of product from labor and capital), the dependency of investments on income, consumption, exports and government debt, and elements of growth theory (e.g. assuming technical progress as a driver for long-term economic development). This module feeds other modules with several important parameters, such as GDP, used to calculate trade flows between the countries, employment and unemployment, used to calculate passenger transport demand, and disposable income, used to calculate car purchase. The employment model depends on the results of the input-output tables and labor productivity to calculate the value created. It estimates employment distinguishing it into full-time equivalent and total employment to account part-time employment. The employment model articulates with the population module to estimate unemployment.

The regional economics module computes the generation and distribution of freight transport and passenger trips. The latter is calculated from car-ownership, employment and population structure for each of the 76 zones the ASTRA model considers.

The foreign trade module is split into two models: trade between the European countries and between the European countries and the rest of the world (accounting for a total of 9 regions). Each model accounts for 25 economic relationships between countries, inputting back into the economy module the sectoral import and export flows.

The transport module uses transport cost- and time-matrices to model passenger and freight modal-split based on inputs of the regional economics module; those matrices depend on factors such as investment, vehicle fleet structure, fuel price and fuel tax. The

Table 1
Summary of the previous relevant studies.

Authors	Country	Method	Period	Objective	Highlights
Baptista et al. (Baptista et al., 2012)	Portugal	Life-cycle analysis	2010–2050	Trace evolution of energy consumption and emissions on the road transportation sector	Efficiency improvements on ICEs and taxation have greater impacts in the short-term than alternative technologies
Braz da Silva and Moura (Braz da Silva and Moura, 2016)	Portugal	Analytic model	Until 2030	Identify EVs diffusion	Taxes applied to fossil-fuels and to conventional vehicles are the most effective measures to increase the penetration of EVs
Seixas et al. (Seixas et al., 2015)	EU	Partial equilibrium model	Until 2050	Assessment of cost effectiveness of EVs	EVs will start to be cost-effective by 2030 if their costs drop 30% below what is anticipated
Magueta et al. (Magueta et al., 2018)	Portugal	Multiple regression analysis	2002–2016	Identify correlations of vehicles sales with macroeconomic variables	Taxation has strong impacts over EVs sales
Lorenzi and Baptista (Lorenzi and Baptista, 2018)	Portugal	Scenario analysis	2015–2030	Assessment of scenarios comprehending renewable energy and technology adoption	EVs are the most effective way to reduce energy consumption and emissions
Alam et al. (Alam et al., 2018)	Ireland	Scenario analysis in COPERT	Until 2035	Assessment of the effects of climate change mitigation policies in reducing air pollution	Reduction in CO_2 emissions by 2035 are not followed by the same magnitude of PM2.5 emissions reductions
Evangelista et al. (Evangelista et al., 2018)	Several countries	Literature review	Up until 2018	Review about the environmental sustainability of third-party logistics service providers	Information and communication technology and performance measurement are still largely unaddressed by the literature
Moriarty and Honnery (Moriarty and Honnery, 2013)	Several countries	Literature review	Up until 2013	Review of measures directed to greening the road passenger transport sector	Technical solutions *per se* are not even close effective at achieving the reductions in emissions that are needed

Table 2
The ASTRA-EC main modules and their variables (Fraunhofer-ISITRT Trasporti e Territorio, 2017).

ASTRA-EC modules	
Module	**Variables**
Population	Household types, income groups
Economy	Employment, input-output tables, investment
Regional economics	Freight transport and passenger trips
Foreign trade	Balance of payments
Transport	Demand, modal split, cost, infrastructure
Vehicles fleet	Road modes
Environment	Pollutants, fuel consumption, CO_2, accidents
Welfare	Macroeconomic, social and environmental indicators

freight transport times are shared with the economy module to enter in the calculation of productivity. Trip volumes (vehicle.km) are determined based on occupancy rates and load factors, which are used to feed the environment and vehicle fleet modules (see below).

The vehicle fleet module describes the vehicle fleet constitution, whereby vehicles are classified by age class, emission standards, fuel and engine size. The car fleet is considered to evolve based on income, population and fuel price changes. Buses, light- and heavy-duty vehicles fleet composition depends on the mileages calculated, which are compared with the average mileages of these vehicles.

The environment module uses outputs from the transport module (e.g. transport volumes per mode and traffic) and from the vehicle fleet model (emission factors are determined based on the vehicle fleet composition) to calculate emissions. It also calculates the total number of accidents from traffic flows and accident rates per mode.

Finally, the welfare module compares and analyses the main macroeconomic, social and environmental indicators (Schade and Krail, 2006).

The simulation is simultaneous, without the need for iterations, making the model coherent. Fig. 1 shows the linkages between the modules.

The modules are dynamically linked, hence variations in one system have impacts in other systems which have effects in the original system. Feedback loops, starting at the micro- or meso-level of the modules (e.g. transport expenditure for one mode and one origin-destination-pair in the transport module) and ending up at the national level (e.g. sectoral consumption), influence the module of origin such that the feedback loop is closed implying to establish interchangeably macro-micro-bridges (e.g. goods flows to GDP and sectoral productivity). For additional insights on the feedback loops, see (Schade and Krail, 2006), since their network is too much interlaced to be able to present it comprehensively here.

As described above, the model accounts many different elements from the transport system (e.g. modal split, constitution of fleet, number of trips, load carried), as well as elements from demography (pyramid segmentation), the economy (e.g. taxes, consumption, trade, investment), the environment (e.g. emissions, externalities) and the social system (employment, accidents). The links between the systems and their elements constitute a complex structure, ruled by means of parameters representing technology stages (e.g. emission factors), social behavior (e.g. elasticity in demand) and existing policies (e.g. taxation). This allows the model to address direct impacts of policies as well as second- and third-level impacts (e.g. reduced air pollution due to less congestion). The economic impacts are addressed thanks to a detailed modelling of the transport sector at the micro- and macroeconomic level, e.g. expenses in transport by passengers are micro-modelled for each mode, giving rise to a certain aggregate consumption, which affects

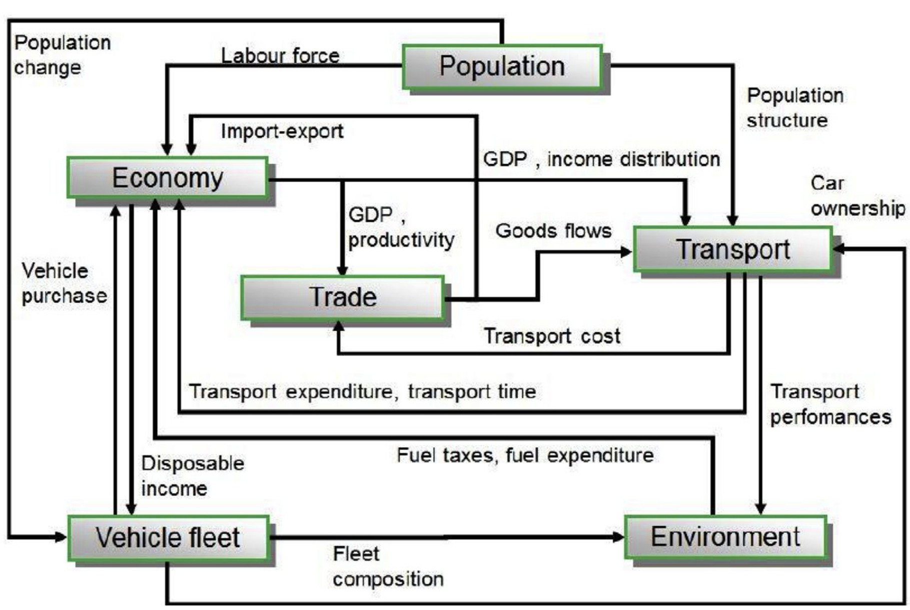

Fig. 1. Linkages overview between the modules of ASTRA-EC. Source: Ref (Fermi et al., 2014a).

GDP. As an example, Fig. 2 shows the implications accounted by ASTRA-EC due to changes in passenger transport costs (Krail and Schade, 2014).

3.1.1. Model calibration

The ASTRA-EC requires the application of corrective factors (calibration parameters) to reduce the difference between its results and statistical records (Fermi et al., 2014b). This calibration procedure ensures that the model describes accurately the reality, even if the picture is simplified, e.g. due to limitations in the simulation of feedback loops and detailed sectoral technologies (Herbst et al., 2012). The ASTRA-EC is a large-scale complex dynamic model, making the calibration not possible in one step; instead, the modules are calibrated individually in sequence, where the outputs of a calibrated module serve as inputs for the calibration of the next module.

The ASTRA-EC is made available pre-calibrated for the period 1995–2010 for the EU27, and individually for each country for the period 2000–2010. Whenever available, statistical records of GDP beyond 2010 should be introduced to allow a better convergence. In this work, the annual GDP for 2011–2016 was introduced in the model. The validation of the casual relationships between indicators considering a large period is an advantage for the long-term impact assessment of transport policies (Fermi et al., 2014a). The deviations in the indicators between the historical records and the model estimations are marginal, always less than a certain tolerance that varies according to the importance of the indicator in the structure of the model (Fermi et al., 2014b). Moreover, the evolution of key indicators between 2010 and 2050 that the model considers, such as fuel prices, matches the projections of the 2013 PRIMES-TREMOVE Transport Model reference scenario (E3ab/at National T, 2014). For additional details, see Ref. (Fermi et al., 2014b), detailing the calibration and validation procedure, and the results, and Ref. (Fermi et al., 2014a), extensively describing the ASTRA-EC model, including its analytic component.

3.2. Model setup

The model allows the simulation of policies that fall into seven categories: Pricing, Taxation, Infrastructure, Internal Markets, Efficiency Standards and Flanking Measures, Transport Planning, and Research and Innovation. Each category encompasses several mechanisms, totaling 23, but not all of them were considered in this study, because some did not fit the purpose of testing the effects on the economy and environment of the application of transport policies to increase sustainable mobility (e.g. the restriction on cabotage measure was not tested).

It was sought that the analysis encompassed a balanced mixed of measures on the two axes of economic instruments and legislative standards, since each kind of approach has its merits. Market-based and command-and-control environmental measures both create financial incentives to reduce pollution – either through taxes or the cost of complying with environmental standards –, but market-based measures give polluters a greater choice of whether reduce harmful activities to the environment, or to remain polluting and be burden by higher costs, in which case the objective fails. Furthermore, the effectiveness of market-based instruments depends on the elasticity of the targeted activities, which is not the case of the effectiveness of legislative measures. However, market-based measures generally conduct to better economic results than legislative impositions, since, by allowing different responses, they usually are cost effective at achieving the environmental goals (Bailey, 2002).

As a third supportive axis, it was considered the application of public investment in transport to promote green-growth, since government green expenditure and resource management is of considerable interest to policy makers. Green investment in infrastructures or new clean technologies, often costly, help to reduce emissions and, additionally, cause desirable rebound effects since it reduces the need for other investments and consumption (Ottelin et al., 2018).

The analysis considers nine mechanisms, grouped into seven policy packages, P1 to P7, according to the scope. Packages P1 to P3

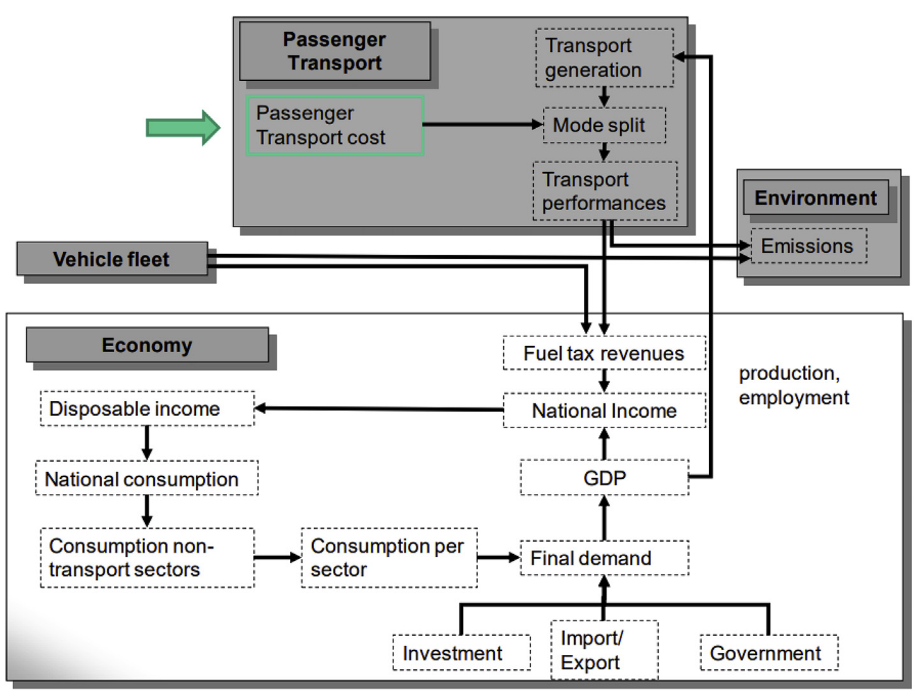

Fig. 2. Implications accounted by the ASTRA-EC model due to changes in passenger transport costs. Source: Ref (Krail and Schade, 2014).

are made of mechanisms of market scope (e.g. introduction of road levies) while packages P4 to P7 are made of command-and-control mechanisms (e.g. imposition of obligations on polluters, such the compliance of standards) and pro-environmental public expenditure mechanisms (e.g. improving public passenger transport or the diffusion of low emission vehicles). It is intended that measures P1–P7 together form a comprehensive planning approach. These mechanisms are detailed in Sections 3.2.1 and 3.2.2, respectively.

Different scenarios composed of policies applied with different strengths were setup: A1 to A4 for the marked-base policies, and B1 to B4 for the command-and-control and public investment policies. The ranges and force of the policies are those considered reasonable according to existing roadmaps and published strategies, such as in Refs. (Transforum Consortium, 2014), (de Stasio et al., 2016) or (Schippl et al., 2016). The scale goes from the more conservative to the more ambitious, limited by what is imposed by the ASTRA-EC model, which depends on the numerical ranges the modules and their dynamic interrelations are prepared to deal with. The evolution between the extremes is progressive. The global scenarios result of the combination of different intensities of sectorial policies.

3.2.1. *Market-based policies*

The market-type measures that were simulated are described below.

- P1 - Congestion Fee – Application of a fee (€/trip) to light passenger vehicles at the entrance of major urban centers. The year of introduction and the fee value vary according to the scenario; Table 3 shows the assumptions made. The fee is applied to all car trips at any time of day.
- P2 - Gas Highway Tax – Introduction of additional levies in motorways (€/vehicle.km) to all kinds of vehicles propelled by petrol or diesel, as Table 3 details. It includes cars, light commercial vehicles and trucks, and it is assumed to be applied from 2020. The model assumes that revenues revert to the state.
- P3 – CO_2 Tax – Implementation of an extra annual tax on the circulation of passenger cars based on CO_2 emissions, to discourage the use of less energy efficient vehicles. The tax is proportional to the excess above 95 gCO_2/km from 2020 to 70 gCO_2/km from 2030. The tax is considered to be introduced from 2020, and the values adopted in the scenarios are shown in Table 3.

The three measures were thought to be a concerted effort aiming to restrain motorized travel demand or vehicle ownership, and their relation is to complement each other: P1 - Congestion Fee acts in urban context; P2 - Gas Highway Tax acts in off-urban context penalizing only conventional vehicles; and P3 – CO_2 Tax penalizes the ownership of the most pollutant conventional vehicles.

Table 3
Market-based scenarios (A1 – A4).

		A1	A2	A3	A4
P1 - Congestion Fee	Introduction year	2020	2025	2030	2040
	Fee (€/trip)	1,00	3,00	5,00	7,00
P2 - Gas Highway Tax	Introduction year	2020	2020	2020	2020
Light passenger vehicles	Tax (€/vehicle.km)	0,01	0,02	0,03	0,04
Light commercial vehicles		0,01	0,03	0,06	0,07
Heavy goods vehicles		0,01	0,03	0,06	0,09
P3 – CO_2 Tax	Introduction year	2017[a]	2020	2020	2020
	Tax (€/gCO_2)	0,544	1,00	2,00	4,00

[a] The tax applied in 2017 is shown for comparison purposes with the scenarios.

Four scenarios – A1, A2, A3 and A4 – were designed, each corresponding to a combination of policies P1 to P3, each policy applied at a given intensity, progressively from the weakest intensities (A1) to the strongest (A4), as Table 3 summarizes.

3.2.2. *Command-and-control and public investment policies*

The command-and-control and public investment type policies that were simulated are described below.

- P4 - ICE Efficiency – Diffusion of more efficient vehicles with regards to CO_2, CO, NOx and PM emissions, assuming that new cars sold comply with the targets envisaged by the EU. Its application is on two levels. Level 1 assumes an improvement in fuel combustion efficiency, leading to CO_2 emissions that comply with the limits shown in Table 4. Level 2 assumes that vehicles comply with the post-Euro 6 emission standard, comprehending emissions reductions of 22% in CO, 28% in NOx and 40% in PM when compared with Euro 6. It is assumed that the new norm enters into force in 2020 for light vehicles and in 2021 for heavy vehicles. Table 5 shows the level assumed for each scenario.

These four measures act on the supply side aiming to complement each other by: P4 - ICE Efficiency acting on all new conventional vehicles; P5 - Urban Logistics acting in urban context, tackling the issue of the urban distribution of goods by logistic service providers; P6 - EV Diffusion providing proper conditions to the emergence of a cleaner supply alternative (cleaner electric and hydrogen vehicles); P7 - Public Transportation acting to meet the travel demand by adding to public collective transport infrastructure and building facilities.

Similarly to the previous section, four command-and-control and public investment scenarios, were created – B1, B2, B3 and B4 –, each corresponding to a combination of policies P4 to P7, each policy applied at a given intensity, progressively from the weakest intensities (B1) to the strongest (B4), as Table 5 summarizes.

3.2.3. *Tested scenarios*

The combination of the market-based scenarios A1-A4 and the

Table 4
CO_2 limits assumed in P4 - ICE Efficiency.

		2015	2017	2020	2030
Light passenger vehicles	g/km	130	–	95	70
Light commercial vehicles		–	175	147	110
Heavy goods vehicles		−25%[a]			

[a] As compared to the average fleet level of emissions in 2007.

- P5 - Urban Logistics – Imposition of a more efficient distribution of goods in urban centers, increasing the load factor of freight transport by light and heavy vehicles, as Table 5 shows. The model assumes that the load factor grows linearly over a period of five years upon the introduction of the policy.
- P6 - EV Diffusion – Stronger deployment of low emission vehicles, e.g. electric, hybrid and hydrogen vehicles. Its application started in 2015 and is made in two levels: Level 1 regards the diffusion of electric and hybrid vehicles (10% of the car fleet in 2050), while Level 2 additionally assumes the diffusion of hydrogen vehicles (2% of the car fleet in 2050). This policy requires an additional investment in research and development in related economic sectors (e.g. electronics and chemistry) and accelerated deployment of charging infrastructures. Table 5 shows the level assumed for each scenario.
- P7 - Public Transportation – Improvement of public collective transport of passengers by bus and rail, improving the quality of service by increasing frequencies and reducing trip duration, resulting in reduced total time spent travelling. Table 5 shows the reduction of total trip duration in percentage, as compared with a business-as-usual scenario, and the year the policy enters into force. The model assumes the reduction is linearly over a period of three years upon the policy implementation.

Table 5
Command-and-control and public investment scenarios (B1 – B4).

		B1	B2	B3	B4
P4 - ICE Efficiency	Level adopted[a]	–	1	2	2
P5 - Urban Logistics	Introduction year	2020	2020	2020	2020
Light commercial vehicles	Load factor increase	5%	10%	15%	25%
Heavy goods vehicles		–	–	2%	4%
P6 - EV Diffusion	Level adopted[a]	–	1	2	2
P7 - Public Transportation	Introduction year	2020	2025	2030	2040
Buses and trains	Trip duration reduction	5%	10%	15%	30%

[a] See the description of the respective measure.

command-and-control and public investment scenarios B1–B4 are shown in Table 6. From the 16 possible arrangements, six were chosen for simulation (marked in gray in the table). The choice considers that market-based and command-and-control and public investment policies of the same strength tended to be applied simultaneously (A1B1, A2B2, A3B3, A4B4). The most unbalanced scenarios between policies (A4B1 and A1B4) were also selected to explore its impacts. Additionally, a baseline scenario, business-as-usual (BAU), was setup, not including any of the policies P1–P7. The driving forces of the BAU scenario align with the 2013 PRIMES-TREMOVE Transport Model reference scenario (E3ab/at National T, 2014), which reflects solely the already existing trends and policies in development of the EU transport system (European Comission, 2014).

- given that ASTRA-EC works at a macro-level, the model has limitations quantifying social impacts that tend to occur at the local level, such as localized air pollution (Fermi et al., 2014b);
- maritime and air transport of passengers are not considered by the model;
- electric mobility modelling is somewhat limited, as ASTRA-EC does not allow the simulation of policies or market conditions leading to very high penetration rates of electric vehicles. Since several European countries have announced their intention to prohibit the sales of conventional cars from 2030 to 2040 – it is not however the case of Portugal –, possibly the penetration of EVs in European car fleets will be higher than what the model is able to account for;
- the ASTRA-EC does not simulate new concepts of passenger transport, e.g. on-demand ride hailing using technology platforms, or autonomous vehicles.

3.3. Limitations

Models are essential tools for economic and environmental analysis, but they are limited. Macro mathematical models, inherently, no matter their sophistication, are approximations of reality, more or less precise according to the robustness of their equations and the unpredictability of what they seek to explain and of the underlying data they rely on. They are broad abstractions limited by the at the time state of the art of science and observations of the past, providing accurate results within a certain tolerance. This means they tend to be less accurate or inappropriate when applied at smaller scales and are less good with turning points.

In particular, the ASTRA-EC model provides results that enable a detailed impact assessment of several economic, transport, environmental and social parameters, nonetheless the following caveats ought to be mentioned:

Table 6
Final scenarios.

stronger scenarios →

stronger scenarios ↓

BAU	B1	B2	B3	B4
A1	A1B1	A1B2	A1B3	A1B4
A2	A2B1	A2B2	A2B3	A2B4
A3	A3B1	A3B2	A3B3	A3B4
A4	A4B1	A4B2	A4B3	A4B4

4. Case study

The study presented in this paper uses Portugal as a testbed. In 2015, the final energy demand in the country was led by the transport sector (41%), followed by industry (28%), residential (16%), services (12%) and agriculture and fisheries (3%) (PORDATA, 2017). Transportation had the highest growth from 1990, when its share was 32%, due to the increased mobility of passengers and goods, mostly by road.

Road represents about 95% of total passenger travelling (93.8 thousand million p.km in 2014), 89% by car (the highest car modal share within the EU) and 6% by bus, and the remaining 5% by train. Compared to 2000, the use of private car grew from 81%, due to the surge in private vehicle owning (it grew c.a. 30% in the same period), bus decreased from 14% and train use remained stable, as Fig. 3 shows (European Commission, 2017). The extension of the road network grew 19% since 2000, especially motorways, which grew 113%. On the other hand, the extension of the train line in operation decreased by approximately 10% (Instituto Nacional de Estatística, 2014).

Portugal employs around 147,800 workers on the transport sector, representing 3.9% of the workforce in the country. The economic value of the sector is 17,700 million euros (10.3% of GDP). Road haulage is the main activity, employing 58,800 workers, followed by passenger transport, accounting for 33,200 jobs, transport auxiliary activities, e.g. transport agencies, infrastructure maintenance and goods handling, employing 28,500 workers, and postal activities, employing 14,600 workers (European Commission, 2017). Fig. 4 shows the share of employment by activity in the transport sector. As for CO_2 emissions, transport accounted for 24% of total emission in 2015 in Portugal; relative to 1990, the amount increased by 61%, mostly due to road traffic (Agência Portuguesa do Ambiente, 2017).

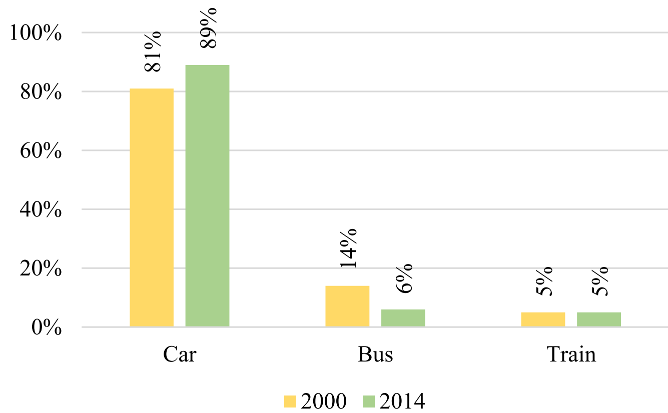

Fig. 3. Comparison of passenger transport by mode between 2000 and 2014 in Portugal (European Commission, 2017).

5. Results and discussion

Below, Section 5.1 shows the results for the business-as-usual scenario, and Section 5.2 for the alternative scenarios, under the scope of Transport, Environment or Economy categories. The effects in the different sectors are quantified by the following variations: in transport, by transport volume (passenger.kilometer or tonne.kilometer) and respective modal shares; in the energy and environment, by emissions of CO_2 and pollutants (CO, NOx and PM2.5); in the economy, by the GDP and net employment.

5.1. Business-as-usual scenario

The business-as-usual scenario anticipates for the period 2015–2050 a 18.9% increase in the volume of total passenger trips, from 106.9 to 127.1 thousand million p.km, peaking in 2040; this is regardless of the expected population decrease, 6.4% in the same period (Instituto Nacional de Estatística, 2015). The modal distribution is not very different: automobile in 2050 will remain the main means of transportation (85%), followed by bus (9.7%) and rail (5.3%). Fig. 5 shows these trends. The number of light passenger vehicles per thousand inhabitants is estimated to increase 17.1%, from 452.8 in 2015 to 530.1 in 2050. Despite this, the final energy demand decreases by 0.7% (from 6.08 to 6.04 Mtoe), and CO_2 emissions by 2.6% (from 18.2 to 17.7 Mton), due to efficiency gains. This is in line with what has been pointed out by (Andrés and Padilla, 2018): positive effects on the EU transport emissions due to improvements in energy efficiency are limited when they are accompanied by growth in the economy and in transport volume.

It is estimated that pollutants (CO, NOx and PM2.5) emissions will decrease by 42%, from 89.3 to 51.8 thousand tons. This is due to the renewal of the fleet by cle aner vehicles, obeying to more stringent emissions standards. Oil tax revenues increase by 31%, from 3.5 to 4.6 thousand million euros, and road tax revenues increase by 52%, from 714 to 1086 million euros. Those are direct consequence of the continuous increase in car use as the main means of transport.

It is estimated that national GDP will increase from 179.5 to 287.6 thousand million euros, representing an average annual growth of 1.72%. Total national employment is estimated to increase from 4.87 to 5.09 million workers, translating an evolution of the active population from about 49% to 59%. Table 7 summarizes these figures.

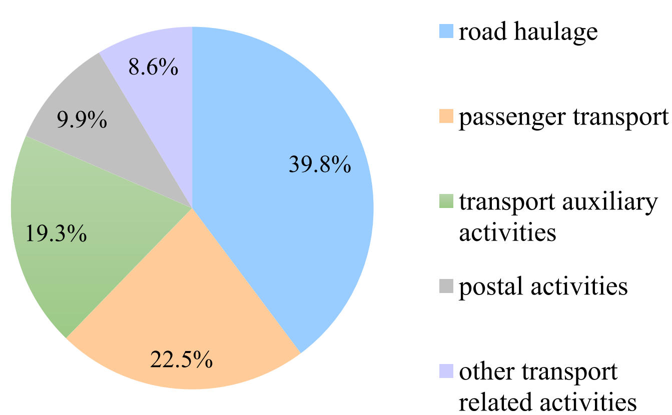

Fig. 4. Share of employment by activity in the transport sector (European Commission, 2017).

5.2. Alternative scenarios

The results for the alternative scenarios detailed in Section 3.2 are presented below: Section 5.2.1 presents the mobility related indicators; Section 5.2.2 the environmental indicators; and Section 5.2.3 the economic indicators. Relative results shown are in comparison with the business-as-usual scenario, unless stated otherwise.

5.2.1. Mobility

In the period 2020–2050, total passenger travelling decreases slightly in all scenarios (due to the inelastic behavior of this indicator), with more expression in A1B1 (−0.8% by 2050) and less in A1B4 (−0.2%). However, there are significant differences in the modal distribution: in 2050 the use of the car is reduced, whereas bus and rail transport increases, as Fig. 6 shows.

The decrease in the use of private car ranges between 2% (A2B2) and 5.4% (A4B1); reductions are stronger with tougher market-based policies, i.e., A4 scenarios, as in A4B4 and A4B1, due to the application of levies on car use. The smaller reduction observed in scenarios A2B2 and A3B3 is related to the application of measures P4 - ICE Efficiency and P6 - EV Diffusion, i.e. higher diffusion of low emission vehicles – see Section 3.2.2, from scenarios B2, which has the indirect effect of lowering the cost of using cars, due to lower taxes. If car use is not reduced so much, then public transportation does not increase as much either, as seen on the corresponding bars for bus and train. These results suggest that a careful analysis is needed when applying measures that promote the market

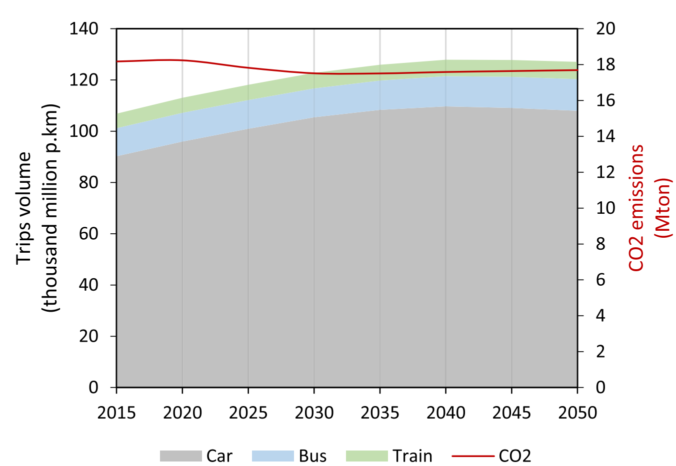

Fig. 5. Passenger travelling evolution by mode in the Reference Scenario.

Table 7
Reference scenarios figures.

	2015	2050
Motorization rate (passenger cars per 1000 inhabitants)	452.8	530.1
Final energy demand (Mtoe)	6.08	6.04
CO_2 emissions (Mton)	18.2	17.7
CO, NOx and PM2.5 emissions (kton)	89.3	51.8
Oil tax revenues (thousand million euros)	3.5	4.6
Road tax revenues (million euros)	714	1086
GDP (million euros)	179.5	287.6
Employment (million jobs)	4.87	5.09

deployment of cleaner vehicles and penalize the use of the dirtier ones, because of rebound effects.

The use of buses increases between 8.1% (A2B2) and 33.1% (A4B4), i.e., the greatest increase in bus transport corresponds to combining the strongest market-based and command-and-control and public investment measures (A4B4). It can also be observed that bus use is similar if one applies a mix of weak market-based and strong command-and-control and public investment mechanisms or vice-versa (A1B4 and A4B1, respectively).

Finally, the use of rail transport increases between 8.6% (A1B4) and 33.8% (A4B1), showing that marked-based measures in A4B1 are more effective at dislocating passenger transport to train than the command-and-control and public investment strategies of A1B4.

5.2.2. Environment

The policy measures tested allow CO_2 emissions reductions of between 2.1% (A1B1) and 26% (A4B4) by 2050, as Fig. 7 shows. These figures are relative to the BAU scenario. Relative to 1990, those figures correspond, respectively, to 53 and 15% increase in emissions – it must be recalled that emissions grew 61% in the period 1990–2015 (c.f. Section 4) –, which can be compared with the environmental objective proposed in the 2011 EU Transport White Paper (European Comission, 2011) to achieve a 60% reduction in the EU transport sector emissions by 2050. Therefore, the proposed measures are by no means enough to achieve this objective in Portugal – for that, a much larger multi-policy approach would be needed, in particular measures aiming at reducing passenger travel needs, an effective way to produce emission cuts (c.f. Section 2) (Moriarty and Honnery, 2013). The petrol and diesel cars sales ban somewhere during the next two decades and the limitation of their circulation within cities, as several countries and municipalities in the EU have been announcing, should certainly be also part of the package – this is a measure that strongly fosters the uptake of the market by EVs, seen as the most effective way to reduce energy consumption and emissions (c.f. Section 2) (Lorenzi and Baptista, 2018).

Fig. 7 also shows that in scenarios without incentives for stronger deployment of electric vehicles (policy P6 - EV Diffusion, scenarios A1B1 and A4B1, c.f. Section 3.2.2), CO_2 is reduced by only 2–4%. On the other hand, if P6 - EV Diffusion is in force, CO_2 reductions are always higher than 20%, showing that to significantly lower emissions it is necessary to combine incentives to public transport use with a much more efficient car fleet. The transition to this more efficient car fleet is completed by 2040, leading to a slowdown in emissions reductions and subsequent stabilization.

Pollutants' emissions of CO, NOx and PM2.5 also decrease in all scenarios (Fig. 8). Without incentives to the diffusion of cleaner vehicles complying with the post-Euro 6 emission standard (policy P4 - ICE Efficiency, in A1B1, A2B2 and A4B1, c.f. Section 3.2.2), emissions decrease less (1–7%), which agrees with (Baptista et al., 2012) (see Section 2). On the other hand, when this policy is implemented, emissions decrease between 22 and 27%. In these scenarios there are diminished returns from 2040 or even a slight increase in emissions, due to an increase in the economic activity. It ought to be underlined that some of the reduction in pollution is expected to take place in urban areas (due to measures P1 - Congestion Fee and P5 - Urban Logistics), where the environmental improvement will be thus more significant than the averaged values presented in Fig. 8.

5.2.3. Economy

The impact of the different scenarios on the GDP is shown in Fig. 9. The evolution of GDP may be divided into four distinct periods: (1) between 2020 and 2027–2028 (depending on the scenario), GDP decreases or grows slightly, since this period coincides with the introduction of the policies; it can be said that, in general, the measures during this period adversely affect the economy; (2) the economy adjusts and starts growing until 2035, (3) platooning in the period 2035–2045; (4) 2045–2050, where growth returns stronger. It must be noted that the effects of policies are dynamic and present delays in relation to its application, making difficult to identify individual effects. It can be said, however, that the mobility transition envisioned in all scenarios lead to long term economic growth: by 2050, the growth is between 1.5 and 3.2 thousand million euros, corresponding respectively to scenarios A4B1 (+0.5% of GDP in 2050, on average + 0.1% of GDP each year) and A1B4 (+1.1% of GDP in 2050, on average + 0.5% each year), suggesting

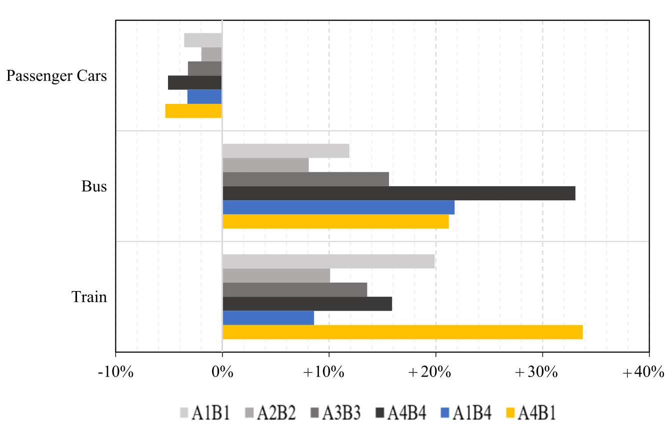

Fig. 6. Passenger transport mode variation in each scenario in the period 2020–2050, as compared to the business-as-usual scenario.

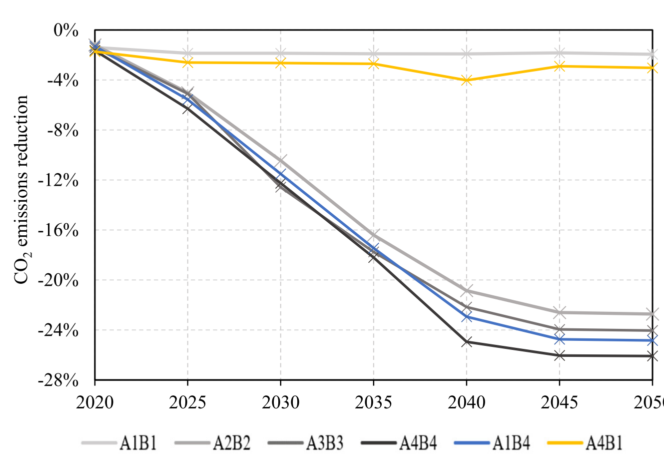

Fig. 7. Transport CO_2 emissions reductions in the period 2020–2050, as compared to the business-as-usual scenario.

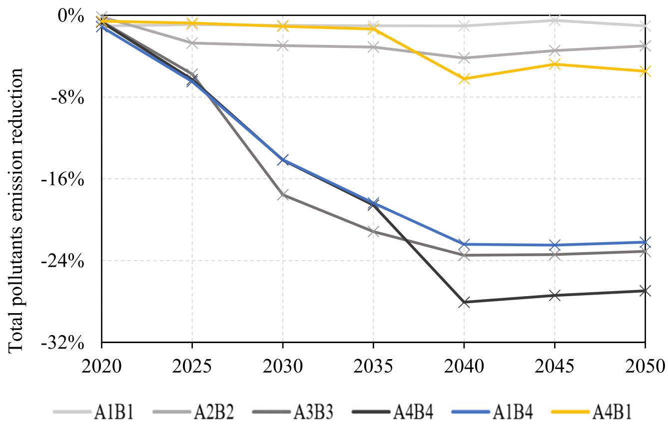

Fig. 8. Pollutants emissions reductions in the period 2020–2050, as compared to the business-as-usual scenario.

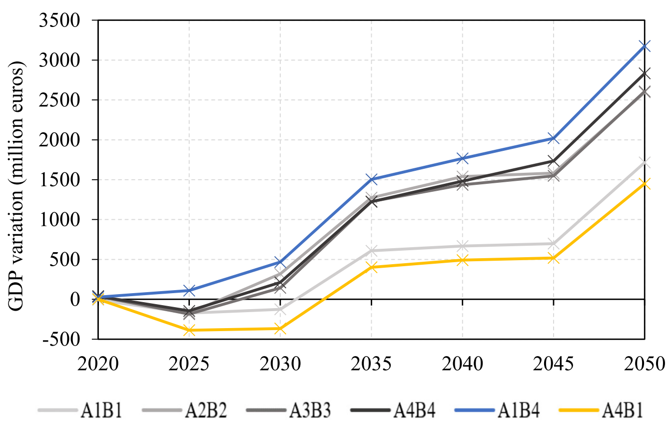

Fig. 9. GDP variation in relation to the business-as-usual scenario.

that smoother marked-type measures (A1) combined with legislative stronger measures (B4) are those that lead to better performance in the economy.

In general, employment figures follow the evolution of economic growth. Fig. 10 shows the employment difference in the period 2020–2050 relative to the business-as-usual scenario. The small decline in the GDP at the beginning of the period has repercussions in the workforce, which is reduced (except in A1B4). Around 2024–2027, depending on the scenario, the number of jobs starts to grow, and in scenarios A2B2, A3B3 and A4B4 the balance becomes positive from 2026 to 2027. As of 2030, coinciding with the good performance of the economy, there is a strong job creation; this is not only in transport, but on the whole economy, since there is indirect and induced job[3] creation. Scenarios A4B4 and A1B4 allow for an increase in employment by 2050 of about 10,000 jobs, c.a. 0.22% of the total workforce.

It can be said that, in the long term, the net effects on the employment of the policies that were tested are positive. Environmental policies shift the structure of employment, so that employment decline related to polluting activities and products are more than off-set by the creation of jobs in less pollutive sectors. This is an outcome from growth in labour intensive green sectors, from the shift of taxes from employment to pollutive activities and

[3] Indirect employment is created in the businesses that supply goods or services to the transport sector. Induced employment is due to the economic impact of the transport sector in the broader economy.

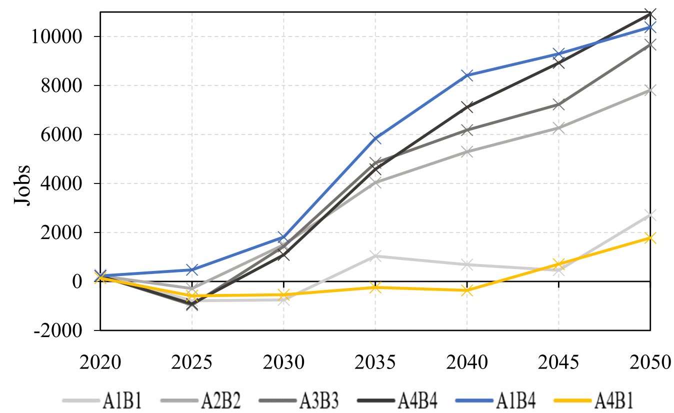

Fig. 10. Employment variation in relation to the business-as-usual scenario.

from growth in green-innovation and -technology (Rayment et al., 2009).

The combination of environmental and economic indicators makes it possible to identify the relationships between CO_2 emissions and employment in transportation and national GDP. Fig. 11 shows for the period 2020–2050 the correspondences between these indicators relative to the business-as-usual scenario for all the scenarios. As expected, there is a high positive correlation ($R^2 = 0.8803$) between GDP and employment (Fig. 11a.), meaning that the correspondence between both is high. The figure also shows that there is a very high co-dependency ($R^2 = 0.8796$) between reductions in CO_2 emissions and employment, such that each 10% in CO_2 emissions decrease corresponds to an increase of c.a. 4% in transportation employment (Fig. 11b.). As for the relationship between CO_2 emissions and GDP (Fig. 11c.), it is high but not so obvious ($R^2 = 0.6926$); the tendency shows that each 10% decrease in CO_2 emissions in the transport sector corresponds to c.a. 0.45% increment of the national GDP.

These results are in line with the general agreement that environmental policies, both market-based and regulatory-based, improve productivity by increasing the efficiency in the use of energy and resources (Rayment et al., 2009). In the case of market-based policies, the application of economic instruments places the transport sector closer to an equilibrium position where resources are allocated more social-efficiently (Banister and Button, 1993). By applying levies on transportation, both transport supply and demand change, and if the tax income is enough to cover externalities, the new equilibrium is socio-economically more efficient. As a result to the imposed tax, demand adapts itself by reducing consumption and adopting more efficient ways of transportation. The induced changes in relative prices stimulates research and development and the adoption of alternative resources, production systems and products (Rayment et al., 2009). However, due to prices rise, these are not wide-accepted policy measures within society (Vieira et al., 2007).

As for regulatory based policies, since they are mandatory to obey, they tend to be highly effective and more easily imposed. Technical regulation forces the market to reduce externalities, but it is thought that this type of measures may distort competition within the market (Vieira et al., 2007), leading to a sub-optimal equilibrium, at least for some time after the measures are implemented. However, after an initial period, and according to the Porter Hypothesis (Porter, 1991), well-crafted environmental regulations lead to better resource usage, triggering innovation that leads to products or services with added value, which generates profits that more than pay off both the costs to comply with the regulations and the innovation ones. That is, the application of

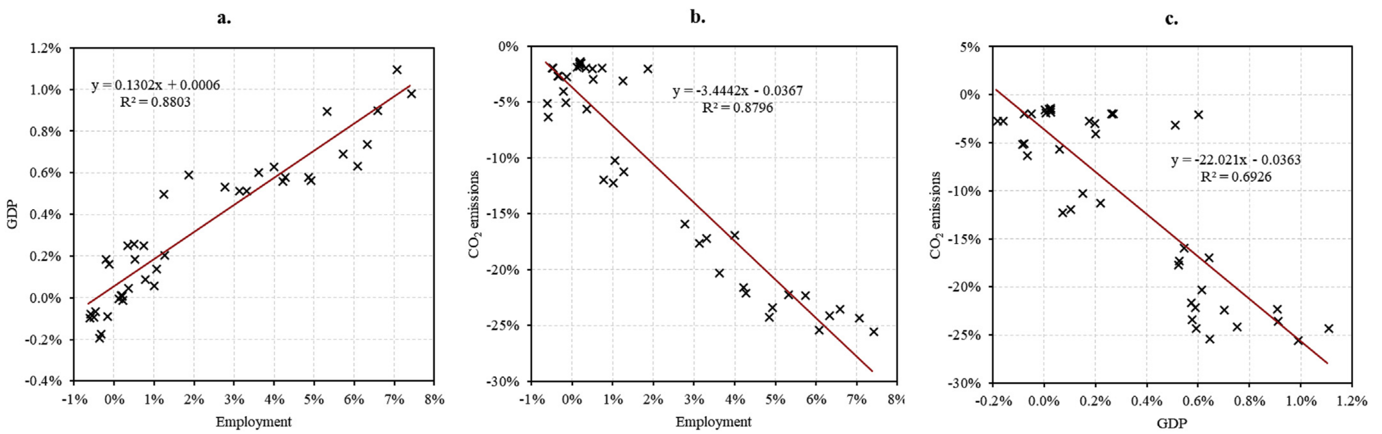

Fig. 11. Relationships obtained in each scenario between variations in the national GDP and employment and CO_2 emissions in the transport sector.

Table 8
Comparative long-term positive effects on mobility, environment and economy in each scenario.

Scenario	A1B1	A1B4	A4B1	A4B4	A2B2	A3B3
Market based policies strength	+	+	++++	++++	++	+++
Command and control policies strength	+	++++	+	++++	++	+++
Effects on						
Mobility						
Private transport usage	✓✓	✓✓	✓✓✓	✓✓✓	✓	✓✓
Bus ridership	✓	✓✓	✓✓	✓✓✓	✓✓	✓✓
Train ridership	✓✓	✓	✓✓✓	✓✓	✓	✓✓
Environment						
CO_2 emissions	✓	✓✓✓	✓	✓✓✓	✓✓✓	✓✓✓
CO, NOx and PM2.5 emissions	•	✓✓	✓	✓✓✓	✓	✓✓
Economy						
GDP	✓✓	✓✓✓	✓✓	✓✓✓	✓✓✓	✓✓✓
Employment	✓	✓✓	✓	✓✓	✓✓	✓✓

Legend: • - negligible; ✓ - little; ✓✓ - medium; ✓✓✓ - large.

regulation stimulates innovation, forcing the entry into the market of new products and services, making regulation an important instrument within a multi-policy approach to make the transport sector cleaner (Vieira et al., 2007).

5.2.4. Summary

The following table (Table 8) provides a summary for policy makers of the compared results in 2050 of each scenario organized according to the effects in each sector. The effects are classified according to their positive impacts. It ought to be stressed that the table pertains only to the long-term effects, although there are non-negligible short-term effects, such as negative ones on GDP and in employment in most of the scenarios (c.f. Section 5.2.3).

6. Conclusions

Transport accounts for a large share of emissions of CO_2 and pollution, facing major challenges over the coming decades. The sector is already undergoing significant changes, and strategic government policies are crucial to push it to the best path. This study developed a framework consisting of multi-policy approach-based scenarios, built on market-based and command-and-control and public investment mechanisms, to enhance the understanding of intersectoral outcomes of transport policies. It contributes to the body of knowledge on the effects of transportation policies in the mobility, the environment and the economy, helping to inform the design of environmental policies. The scenarios, which are for Portugal until 2050, were tested in the ASTRA-EC, a simulation model based on a unified dynamic approach between sectors of economy, and the results were compared with a business-as-usual reference case. The effects in the different sectors were quantified by variations in transport volume and respective modal shares, by emissions of CO_2 and pollutants, and by changes in the gross domestic product (GDP) and net employment; a relationship between CO_2 emissions avoidance and labour creation on the economy and GDP growth was established.

The results show that, by 2050, the total number of passenger trips will be similar in all scenarios but there are important differences in modal share: car use is reduced by 2–5%, bus use increases by 8–33%, and train by 9–34%, depending on the scenario. Stronger market-based policies, such as the application of levies on car use, lead to the most significant changes. It was observed that combining measures that promote the market deployment of clean vehicles and penalize the use of the dirty ones may have a rebound effect on car use, suggesting the need for a careful analysis in these cases.

The CO_2 emissions are reduced by between 2.1 and 26%. Stronger reductions are linked to the application of policies promoting the deployment of electric vehicles, suggesting that to significantly curb emissions it is necessary to combine incentives to public transport use with a much more efficient car fleet. The deployment of strong specific targets, for cars, buses and logistic service providers, and respective enabling policies, aiming to ensure that zero-emission vehicles will be adopted in much larger numbers, is essential. Those policies should target innovation, by increased investment in it, the automotive car makers, setting up specific incentives for manufacturers to develop and sell zero- and low-emission vehicles, especially in markets where these vehicles

penetrate less, and the end user, through the promotion of better mobility habits and incentives to the adoption of clean cars. Certainly the push in Europe for greener vehicles through the revision of the Clean Vehicles Directive is a good step and example in that direction.

It was also observed that the promotion of cleaner vehicles complying with post-Euro 6 emission standards allow for less 22–27% of pollutants emissions. In urban areas the improvement is larger than this. It means that the improvement of the fleet still based on conventional vehicles is also part of the solution. For that, accurate and comparable information on CO_2 and pollutants emissions and on fuel consumption over the lifecycle of new cars should be made available, using common and robust methodologies based on measured, as opposed to declared, values. On the other hand, it was found a relationship such that each 10% in CO_2 emissions decrease corresponds to an increase of c.a. 4% in transportation employment and of c.a. 0.45% of GDP, which means that the proposed policies to adopt are beneficial to the economy. Smoother marked-type measures combined with stronger legislative measures and public investment are those that lead to better performance in the economy.

Despite these results, since it is expected growth in the economy and in transport volume, in absolute terms emissions in 2050 in Portugal increase by 15% in relation to 1990 in the best-case scenario. This falls much short of the environmental objective proposed in the 2011 European Union Transport White Paper to reduce emissions by 60%, meaning that for the country to achieve this goal it is needed a much larger and ambitious multi-policy approach. It should certainly be part of it the ban on sales in Portugal of new petrol and, especially, diesel cars, and the limitation of their circulation within cities, as several other countries and municipalities of the European Union have been announcing.

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